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Life cycle inventory and risk assessment of genetic modified perennial ryegrass in a technology foresight perspective

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Abstract. Due to the complexity and advanced nature of modern biotechnology and to its content of risk and ethic matters it is necessary to face the challenge of making the prospect comprehensible and transparent to society. Using life cycle inventory (LCI), expert panels and weighted expert questionnaires, a methodological approach is suggested to analyse the uncertainties that the biotech industry and the authorities face when implementing genetically modified (GM) crops. These uncertainties embrace scientific rationality regarding technological development and risk assessments, as well as ethic political and social matters, which are based on more dispersed matters. In a test case on the development of a GM-ryegrass (that is incapable of producing stems and flowers during grassland farming) incorporated answers to a questionnaire from different types of experts and stakeholders identified four drivers as the most important and uncertain factors for the future direction of GM crops: 1) public participation in regulation, 2) utility value for the consumers, 3) being first to market GM-ryegrass, and 4) an efficient professional network. Based on the identified drivers several scenarios were constructed, of which two are presented in the report.

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Preface

The present study can be characterised as a feasibility study in the field of technology foresight analysis of genetically modified (GM) crops. The aim of the study is to contribute to the development of a technology foresight framework for analysis of features and drivers related to the development of GM crops. The case studied is a GM-ryegrass, which is incapable of producing stems and flowers during grassland farming.

The authors wish to acknowledge DLF-Trifolium A/S and our colleagues at Risø National Laboratory for their support to the study. Further, we wish to thank the expert panel and the respondents of the questionnaire for their valuable contributions.

1 Introduction

Genetically modified (GM) crops are now common on the fields of North America and in some other parts of the world. However, in Europe these crops are met with uncertainty and scepticism and have only to a very limited extent found their way to the fields and the markets. The reason for this is an uncertainty about the risks and consequences of growing GM crops and difficulties in reaching consensus about coverage and application of risk assessments concerning GM crops.

In Denmark there is an increasing interest in the safety of food production systems and a common attitude is that the application of gene technology will reduce the quality of food and furthermore pose a threat to ecosystems (Andersen & Iversen 1998). On the other hand, the food producers are focusing the benefits and their point of view is that the application of GM crops will increase the food quality, reduce the production expenditures and be beneficial to the environment.

At present time consumers do not seem to distinguish between the process of genetic engineering and product of genetic engineering, which may play a significant role for the formation of consumer attitudes and, eventually, acceptance of genetically modified foods. However, the prevailing presumption by the industry is, that the public hesitance towards the utilisation of GM crops can be eliminated through consumer education and the establishment of scientific credibility for companies engineering GM crops (Swords 1999), is probably erroneous for the following reasons:

- Consumers in many European countries apparently oppose genetically modified foods also for ethical reasons (Bredahl et al 1998, Eurobarometer 52.1).
- Consumers are concerned about the disadvantaged by the potential monopoly of multinational biotech companies (e.g. Mannion 1995).

Analysing the consequences of deliberately releasing a GM crop into the environment is an extremely complex task and in some cases even impossible. From a societal perspective, it is therefore necessary to take a precautionary approach, as it remains important to ensure that new hazards are identified and appropriate measures implemented.

The awareness of the impact of new technologies on societal and industrial development has expanded the concept of technology foresight (TF) in several countries in recent years (Martin 1995). The hazards posed by GM crops to natural and agricultural ecosystems may be characterised using life cycle assessment framework (LCA). LCA was primarily developed in the applications to industrial product systems. Recently the concept has been used for LCA of food stuffs (Weidema & Mortensen 1996). Although several research groups are beginning to apply LCA to agricultural systems methodological difficulties are still far from being solved (Audsley 1997) and there is a need to develop a simple way of communicating the results of LCA with out sacrificing credibility.

The present feasibility study has been inspired by the ambitious project "Novel high value ryegrass for future sustainable agriculture" initiated in 1998. The development of the genetic modified ryegrass is a joint research project between the producer of clover and grass seed, DLF-Trifolium A/S, and the Plant Biology and Biogeochemistry Department at Risø National Laboratory. The overall objective is to produce a ryegrass, which is incapable of producing stems and flowers during grassland farming (biological encapsulation). The stems and flowers have a high content of lignin[1] and consequently the lignin content will be lower for the transgenic ryegrass compared to the conventional ryegrass enhancing the nutritional value of genetic modified grass. The idea is to improve digestibility of ruminants[2] by eliminating stem production during grassland farming as the stems of ryegrass contain high amounts of low disgetible lignins.

2 Aim and approach

The aim is to prepare a feasibility study on the application of the LCA approach in TF studies concerning agricultural systems with a genetic modified perennial ryegrass as case. The study is a contribution to the work concerning development of methodologies for life cycle studies and risk assessment of future crop production in a technology foresight perspective.

The method used is a modified life-cycle inventory (LCI), which serves as a platform for the selection and prioritising of drivers and the construction of scenarios. The objective of the analysis is to develop methodologies for strategic planning and regulatory decision-making. The approach involves the comparison of a conventional perennial ryegrass system and a hypothetical system with genetic modified perennial ryegrass to identify and discuss pros and cons for the GM-ryegrass.

The study comprises the following steps:

- <u>System modelling</u>: LCI is the basis for determining the functional units of the system and the starting and ending points of the life cycle. A grass field system is as many other agricultural systems a complex open system with several loops, inputs and outputs, and defining system boundaries is a subjective choice.
- <u>Expert panel</u>: Identifying experts per se is an important assignment if the analysis is to be a success, and in this study the LCI is a supporting tool for this purpose. The experts are selected to represent key stakeholders.
- <u>Scenarios and questionnaire</u>: To build scenarios it is necessary to find major drivers. This was done by letting the expert panel brainstorm over a trigger question related to distinctive time phases from development to marketing of the GM-ryegrass. The brainstorm revealed a number of drivers and among these the most important were evaluated by a larger forum of Danish experts and stakeholders using a questionnaire. Scenarios were constructed by use of uncertainty intervals of the uncertain drivers.

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1 Lignin is a component of the secondary cell wall of plants. The digestive enzymes of the host animal do not break down lignin.

2 Mammals having complex multichambered stomach; uses forages primarily as foodstuffs.

3 Methods

3.1 Life cycle assessment (LCA)

LCA is a science-based, essentially comparative environmental assessment and managing tool for product systems (Klöpffer 1998). The life cycle concept is a "Cradle to Grave (to Cradle)" approach to think about products, processes and services. It recognises that all product life cycle stages (extracting and processing raw materials, manufacturing, transportation and distribution, use/reuse, and recycling and waste management) have environmental and economic impacts. According to ISO 14040 LCA is a technique for assessing the potential environmental aspects and other potential aspects associated with a product/service, by .

- compiling an inventory of relevant inputs and outputs,
- evaluating the potential environmental impacts associated with those inputs and outputs,
- interpreting the results of the inventory and impact phases in relation to the objectives of the study.

LCA development began in the late 1960s with a technique designed to analyse resource utilisation, e.g. energy and materials using an engineering-based mass balance accounting approach. This balance sheet of material and energy inputs and waste and emissions output is called a life cycle inventory (LCI). LCA first accelerated during the energy crises of 1970s, and, again for a short period in the late 1980s and early 1990s, with attempts to use LCA for environmental marketing claims. However, most LCA comparisons were inconclusive and rarely demonstrated clear differences. Nevertheless, there are still ongoing efforts to utilise the inventory to make comparisons and to declare which product is "environmentally superior". The capability to conduct such an assessment with any scientific validity is confronted by LCA's engineering accounting procedures, use of simplifying assumptions, and employment of subjective judgements to circumvent scientific barriers. (Owens 1997).

It is obvious that the LCA approach can be (and has been) used in the design and development of new products and services. The purpose of LCA with respect to development of new products and services can be:

- to estimate the impact of the product/service with respect to the selected inventories
- to describe the complexity of the system to ensure that all relevant issues are considered
- to identify the critical parts (hot spots) of the life cycle chain to include e.g. environmental aspects at the early design stage to avoid non-appropriate design developments
- to compare alternative solutions
- to structure and build up information in order to identify knowledge requirements, e.g. with a view to R&D planning
- to prepare a framework for a focussed discussion between involved parties
- to support strategic decisions about future developments what concerns process developments (single elements of the life cycle chain) and more thorough investigations of possible systems developments.

The basis of an LCA study is an inventory of all the inputs and outputs of the different processes that occur during the life cycle of a product (LCI). This includes the production phase, the life cycle processes include the distribution, use and final disposal of the product.

It is important to recognise that LCA is still in development and the multitude of different applications of LCA hinder use of one universal method. LCA methodologies therefore comprises a set of different methods and approaches within a general framework. The specific choice of methods depends on the purpose of the study (Lindfors et al 1995).

3.2 Technological risks

Technological risk is not a single monolithic quantity. Even under the most reductive analytical approaches, it is conceded that risk is a function (e.g. the product) of two variables - the probability of a hazard and it's consequences. Normally, the risks associated with any individual technology requires the aggregation of series of different hazards and consequences.

In relation GM crops, it is clear that the regulatory debate encompasses a wide range of disparate issues, see Table 1.The crucial point to many of these issues is that they are measured on different dimensions, and that many of them are irreducible qualitative in nature. The relative priority attached to the different dimensions of risk is intrinsically a matter of subjective value judgement. These properties of multidimensionality and incommensurability are crucial and intractable features of technological risk (Stirling 1999).

Table 1. Different aspects of technological risks - GM crops (Stirling 1999).

Broad issue	Class of effect
Environment	Biodiversity. Chemical use. Genetic pollution. Wildlife effects. Unexpected effects. Visual. Aesthetics.
Health	Allergenicity. Toxicity. Nutrition. Unexpected effects. Ability to manage.
Agriculture	Weed control. Food supply stability. Agricultural practice.
Economy	Consumer benefit. Benefit to processor. Socio-economic impact.
Society	Individual impact. Institutional impact. Social needs.
Ethics	Fundamental principles. Knowledge base.

Fundamental controversies in the biosafety debate are more often about the hazard identification than about the risks. Hazard identification is the attempt to recognise possible unwanted effects of some endeavour. When a particular GM crop is applied in the field the question is what consequences may be expected. Biosafety controversies can be interpreted as disagreements between experts about what is to be a sufficient set of relevant questions for the purpose of hazard identification of GM crops. (van Dommelen 1999).

The terminology ecological risk assessment covers mainly an identification of hazards of transgenic spread from the GM crop to the surrounding natural vegetation and the subsequent consequences for the ecosystem. The legal requirements concerning introduction of GM crops to field systems comprises an assessment of environmental, ecological and health risks. The risk assessment is based on the intentions of the so-called precautionary principle aiming at a high safety level through a "case-by-case" review of GM crops and a stepwise procedure for introduction of GM crops to field systems.

If transgenes spread from cultivated fields to surrounding natural vegetation they may effect the environment (e.g. Rogers and Parkes 1995; Snow and Palma 1997). Two situations are commonly discussed, either that the crop itself, by expressing the novel trait, may become more feral and invade non-cultivated plant communities (e.g. Crawley et al. 1993), or that the transgene by spontaneous hybridisation and introgression incorporates in the gene pool of related weedy and wild plants (e.g. Mikkelsen et al. 1996). Once spread to other ecosystems, the fate of the transgene and transgenic plants will depend on the trait that is expressed. Some transgenes may be nearly neutral in nature with no foreseeable effects on the ecosystem. Other transgenes may influence important population-regulating processes, e.g. survival under stress, and the recipient population may increase and cause major fluctuations and changes in the ecosystems (e.g. Rogers and Parkes 1995; Snow and Palma 1997). To minimise the spontaneous spread of transgenes from the fields, breeding companies are presently developing transgenic plants with a reduced or blocked sexual reproduction; this approach has been termed biological encapsulation.

3.3 Technology foresight (TF)

It is generally acknowledged that the accelerating development of new technologies will have a profound impact on society in the years to come. This opens up a range of challenges and opportunities for society, industry and individuals, but it also gives a higher level of uncertainty about the future. Hence, TF studies have attracted renewed interest in many countries and industries.

TF is the process and dialog involved in systematically attempting to look into the longer-term future of science, technology, economy and society with the aim of recognise and exploit generic trends of relevance for the technology in question. TF is an array of techniques that can support the decision maker in the evaluation of needs and desire for a certain technology to develop in the future. (Martin 1995).

The first step of the TF process is technology mapping, which is a categorisation and classification of the technological landscape with the purpose to prepare an overview of the object of the analysis. In parallel technology scanning is carried out with the overall goal to seek major distinguishing features and drivers in the technological landscape. Technology mapping and scanning together provide one of the essential elements of a strategic technology analysis. In that perspective emphasis should be laid on the structure of technology mapping and scanning, but according to Wyk (1997): "Even the most comprehensive recent texts on strategy, typically running to one thousand pages and offering many technology based cases, do not offer advice on structured technology scanning - in some cases the subject is not even mentioned". In this study, the method used for technology mapping and scanning was a modified LCI, which served as a platform for the identification of important features and drivers

Technology scenarios can be defined as stories describing different but equally plausible futures. They are developed using techniques that systematise the perception of alternative futures. Peter Schwartz (1996) talk about identification of possible drivers (e.g. a novel technology) that drive the plots of the scenarios. Drivers effect the scenarios in both obvious and subtle ways and some are more significant than others, e.g. public perception of a technology can often be most critical because the technical risk assessment provided by experts and scientists is not always addressing the issues considered to be essential from a consumer point of view.

The scenarios are projections of a potential future. They are combinations of what might happen and assumptions about what could happen. Thus, projections should not be confused with predictions: A projection should be interpreted as one view of the future that is based upon specific information and a set of logical assumptions (Fahey & Randall 1998). TF and technology scenarios are decision support characterised by preparation and evaluation of scenarios, where objectives of different types and values are weighted out. The main components of a scenario are:

- description of the problem
- identification of the main drivers
- evaluation and selection of drivers according to: i) impact (significance), and ii) uncertainty (variability)
- establishment of the scenario logic
- development of a number of scenarios
- preparation of short stories for each of the scenarios.

3.4 Social theories

A central issue in a prospective study of genetic modified perennial ryegrass is risk assessment, risk perception and risk acceptance as drivers related to the application of the grass. These drivers are multidisciplinary in nature, and in order to treat them in appropriate manner, social theories on technological risks can provide an input, and this section shall be regarded as an inspiration source for that purpose.

Two prominent social theories have been shaping the discourse of environmental politics during recent years. Ulrick Beck's risk society theory (1992) contends that conventional definitions of social class are losing their significance in advanced nations due to success of welfare state in reducing economic scarcity. As societies transition towards late modernity new social cleavages are increasingly coming to be defined by the distribution of technological risks, where these threats are fundamentally different from those that existed earlier: 1) they are undetectable, 2) they can be limited neither in time nor place, i.e. they are capable of transcending generations, 3) they are not accountable according to established rules of causality, blame and liability and cannot be compensated or insured against. Modern industrial society is changing from one based on the distribution of "goods" (material products) to one based on the distribution of "bads" (risks). Shortly described, the driver in the class society can be summarised in the phrase "I am hungry" whereas the collective disposition of risk society is expressed in the statement "I am afraid". Standing in contrast is the theory of ecological modernisation originally advanced by Joseph Huber outlining a hyper-rational strategy for correcting the ecological flaws of contemporary production and consumption practices. Ecological modernists emphasis the role of strict governmental regulations to promote innovation in environmental technology: 1) the key element in executing this transformation is a switchover to the use of cleaner more efficient, and less resource intensive technologies through a process of "super-industrialisation", 2) ecological modernisation relies on the implementation of anticipatory planning practices, the precautionary principle, 3) successful execution of this approach depends on the organisational internalisation of ecological responsibility (Cohen 1997).

Cohen (1997) has attempted to formulate the risk society and ecological modernisation perspectives into a unified theory of social transformation. The proposition that the theories on risk society and ecological modernisation are positioned in opposition to one another can be illustrated as presented in the two-dimensional typology presented in Figure 1. The horizontal axis measures in conceptual terms, environmental and technological security, and the vertical axis delineates development and ranges from typically third-world, pre-modern societies to advanced industrial and post-industrial nations.

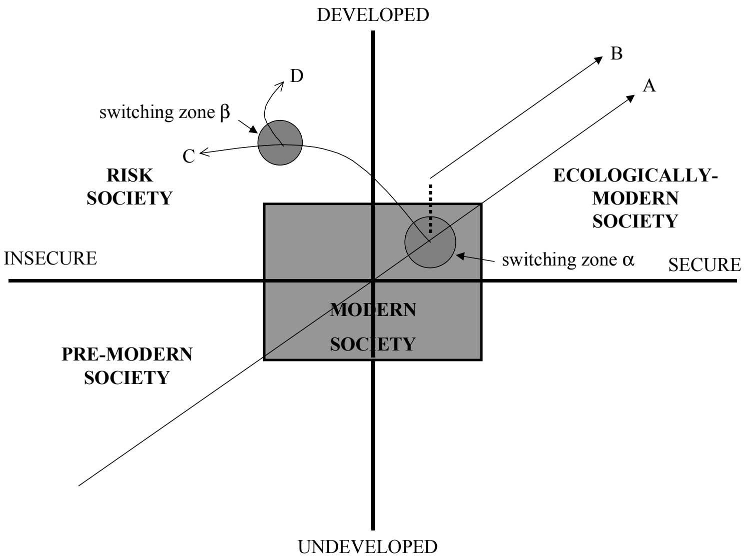

Figure 1. Technological-environmental risk and development (Cohen 1997).

The diagram's central cell represents the stage of the conventional development trajectory in which societies become modern. Risk in modern society is characterised by a critical trade-off in which societies experience an increase in their proficiency for managing natural hazards, but are forced to confront acute and chronic threats arising from the widespread propagation of inadequately-controlled technology.

Development theorists have typically posited that the route to a less environmentally destructive form of social organisation is a linear extrapolation of the customary growth trajectory identified by Path A in Figure 1. However, adherents of this deterministic approach fail to recognise that ecological modernisation is neither preconditioned nor inevitable. To climb into the upper right-hand quadrant, a society must substantially modify its institutional structures, develop new policy tools, and adapt its lifeways to accommodate environmental limits. These adjustments require a society to disengage from its modern past and make the discontinuous leap to the trajectory represented by Path B. The opportunity for a ecological modernisation occurs when a society reaches switching zone α (Figure 1). This zone is marked by a period of indeterminacy during which a complex process of social negotiation takes place to evaluate alternatives and assess political, economic and cultural capabilities. However, in contrast to the assertions of some of its proponents, the transformation to ecological modernity is not assured and failure to make the necessary jump will cause a society to assume an alternative trajectory, labelled as Path C. This is the route of the risk society, characterised by erratic economic development and increasing lay insecurity arising from a preponderance of inadequately-managed hazardous technology. Risk societies are not consigned, however, to face a future of indefinite apprehension as there exists an opportunity for them the chart a development course that enables them to overcome their chronic anxiety. This option, referred to here as the trajectory of the "self-correcting risk society", is depicted Path D, which becomes accessible at switching zone β (Cohen 1997).

Healy (1997) presents the view that modernity has not ended but that, to continue, it must fundamentally change. From this perspective, classical modernity, the modernity of which industrial societies are part, is being replaced by reflexive modernity (Beck 1992). This is characterised by reflexive modernisation in which all aspects of contemporary life are sensitive to reappraisal and reevaluation as a result of constantly emerging new knowledge and information and the changing values and priorities that results from this. In this perspective, the reflexive nature of modernity is exemplified by the developing critical appreciation of science and technology, motivated most fundamentally by the paradoxical role of science and broader technological development in both the creation and potential solution to contemporary risks. Reflexive scientisation, involves science turning its organised scepticism on itself as a means to enable effective criticism of science from within. This idea holds that scientists are the best equipped to critique science and that such a critique will facilitate the cessation of the risks associated with technical advance. Wynne (1996) has recently formulated a critique of Beck where he regards Beck's theories as "excessive realism" with regard to the risks exposed. While for Wynne it is the social or broader cultural construction of the risks that is of central concern, Beck stresses the urgency that he perceives to be substantiated by (natural) science. This difference in focus, between the "reality" and the "construction" of temporary risks, goes to the nub of the divide between the social and natural science.

According to Webster (1999) foresight can be seen to express the attempt by the state to socially manage the uncertainties generated by the transition of technologies within the contemporary innovation system while fostering the heterogeneity and risk-laded nature of this system. Insertion of foresight visions and practices in modern institutions is highly problematic, and indicates a disalingment between the modernist provident state and the late-modern negotiation state. Ultimately, the risk society is one which produces innovation policies such as foresight, which "manufacture" risk, while simultaneously, fosters practices on the ground which attempt to prevent them. New technologies, and their associated techno-economic networks, are caught between these two, and can only hope to innovate successfully, when they achieve a degree of socio-technical alignment between them.

3.5 Life cycle inventory and risk assessment in a technology foresight perspective

Technology assessment and environmental impact assessment have been developed through separate paths and traditions, and there is a lack of synergism between them, which perhaps stems from the prospective (technology assessment) versus reactive (environmental impact assessment) divergence of the two activities (Loveridge 1996).

The LCA concept is belonging to the group of environmental impact assessment methods, and a similar kind of trend can be observed concerning synergism between LCA and scenario development. Scenarios are in one way or another an integral part of any LCA, but they are not always being dealt with explicitly and there has so far been no general LCA framework or procedure available on the systematic development of scenarios. Two basic approaches of scenarios in the context of LCA studies are identified: What-if scenarios and Cornerstone scenarios. What-if scenarios are used to gain operational information and to compare two or more alternatives in a well-known situation with a short time horizon where the researcher is familiar with the decision problem and can set defined hypothesis on the basis of existing data. The Cornerstone scenario approach offers strategic information for long term planning, new ways of seeing the world, and also guidelines in the field of the study. (Pesonen et al 2000).

One of the elements of the present study is to prepare a framework for comparative analysis of the application of the genetic modified ryegrass and conventional ryegrass. Any product, e.g. genetic modified perennial ryegrass, aims to provide a user with a specific function, i.e. it is the function provided to the user that is of prime interest. All LCAs thus intend to describe and assess the impacts associated with a function and not a product or a service. This function also defines, at least in a broader sense, the system to be studied. A comparative LCA only gives meaningful results if alternative systems or developments fulfilling the same function is compared (Lindfors et al. 1995 and Wenzel et al 1997).

The present study involved a discussion of a conventional perennial ryegrass system compared to a hypothetical system with genetic modified perennial ryegrass. As one of the systems is hypothetical, it has been chosen to perform a qualitative What-if discussion of the two systems on basis of a life cycle inventory of the conventional ryegrass system. The structure of the LCI/TF approach of the two ryegrass systems is presented in Figure 2.

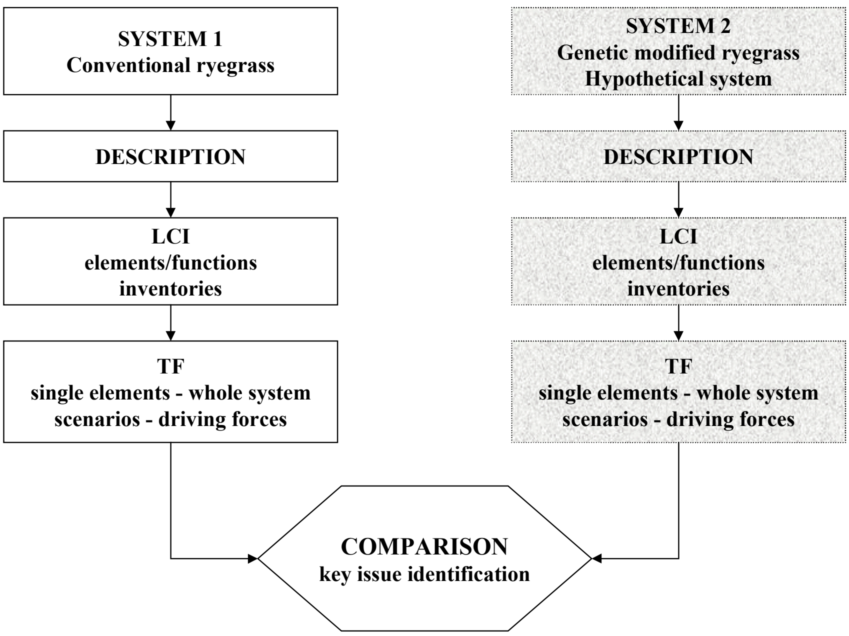

Figure 2. LCI/TF of ryegrass system.

4 Perennial ryegrass

Perennial ryegrass (*Lolium* sp.) is considered the premier quality pasture grass species throughout the world, having a higher digestibility than other temperate perennial grass species (Pysher & Fales 1992). It is considered to be a high quality forage where its relatively high nutrient contents, palatability (i.e. tastiness) and digestibility make these species highly valued for all types of ruminants. It is valued for high yield potential, fast establishment, long growing season, reduced tillage renovation applications, and use on heavy and waterlogged soils. The most common legumes found in pastures are the clovers (*Trifolium* spp.), and are nutritionally superior to grasses in protein and mineral content. The clover gives rise to a 10-15% increased utilisation of the grass by the cow.

Forage grass is by far the largest agricultural crop in the EU, occupying a total of 60 mill. ha. Compared to other agricultural crops, the grass crop has a very positive environmental profile by being perennial, facilitating reduced mechanical treatment and very limited seepage of nutrients. Also, the use of pesticides is very limited and a large diversity of wild plant species, insects and animals thrive well in grass fields.

The case study is focusing on application of ryegrass in the food production chain, and the application of ryegrass for turf, lawns, football grounds etc. and seed production is excluded. The analysis is limited to ryegrass for forage:

- Pasture: The primary use of perennial forage-type ryegrass in the U.S. is for lactating dairy cows on pasture. It is also the principal feed source for dairy cows in New Zealand and is important for diary production forage systems in Great Britain and Europe (Balasko et al. 1995). It is suitable for all classes of livestock, especially those with high nutrient requirements such as young growing animals.
- Hay: As a hay crop, ryegrass yields may be relatively low unless considerable time is allowed for forage accumulation for fall harvest. Ryegrass plants contain less dry matter and therefore require long curing time before baling relative to other cool-season grasses.
- Silage: Perennial ryegrass is often harvested for silage. It makes up a considerable portion of diary quality grass silage in many parts of the world. Biodegradation treatment of lignin in silage can increase retention of polysaccharides (Morrison et al. 1984).

The two primary outputs from the system are:

- Milk: Perennial ryegrass silage has high nutritional quality, but performance of lactating cows indicated that the forage was suboptimal for supporting high milk production when compared with alfalfa (Hoffman et al. 1998). The perennial ryegrass may be suboptimal because it does not stimulate high amounts of dry matter intake in lactating cows. In large amounts, fibre may fill the rumen, limit intake of energy and constrain milk production. Fibre is important for dairy cows because they stimulate rumination and promote a healthy rumen environment for bacterial growth. Lack of fibre can lower milk fat test and production and cause metabolic problems, such as rumen acidosis and infection diseases.
- Meat: Perennial ryegrass is suitable for all classes livestock, especially those with high nutrient requirements such as young growing animals.

The perspectives for agriculture and environment of the GM-ryegrass can be summarised as:

- Improved quality: the lack of production of low digestible stem tissues will drastically improve forage digestibility, and the introduction of genes conferring improved disease resistance, palatability, digestibility and amino acid composition, will improve the overall quality and value.
- Low input environmentally benign crop: the availability of high quality grass throughout the growing season will increase the overall fodder value of the crop and reduce the need for additional animal feed in the form of costly cereal based concentrates. This again will have a secondary feedback on the use of pesticides and fertilisers.
- Biological encapsulation: avoidance of dispersal of active transgenes to weeds and wild populations.
- No pollen production in the grassland crop: since ryegrass pollen is a severe allergen the lack of pollen production has additional human health implications.

A grass field system is as many other agricultural systems a complex open system with several loops, inputs and outputs. Some of the system elements are controllable but several are not and the farmer must continuously supervise the production and its condition and take action if needed.

Figure 3 contains a diagram of a grass field production system showing the relations and interactions between the different activities at an overall level.

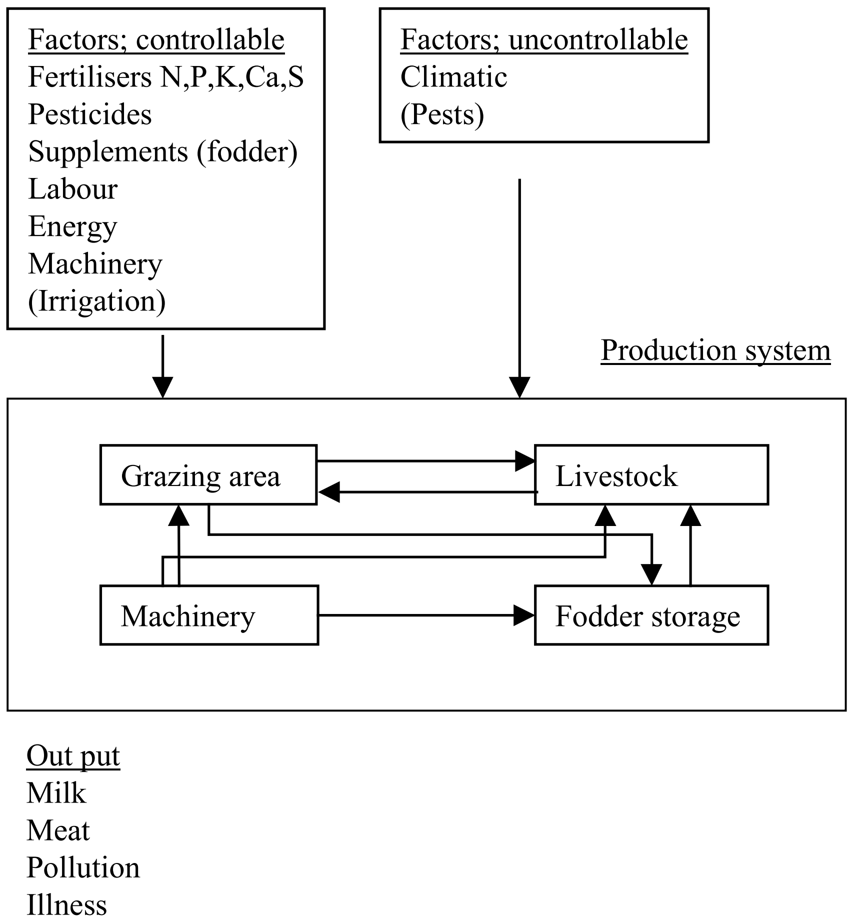

Figure 3. Overall description of a grass field system.

5 Prospective study

The overall structure of the prospective study is indicated in Figure 4.containing the following steps:

- LCI - defining system boundaries (section 0)
- designation of expert panel and identification of drivers (section 5.2)
- prioritising drivers by weighted questionnaire (section 5.3)
- building scenarios (section 5.4).

The fifth step of the procedure "Formulation of strategy" was not included in the present study. The methodological framework presented has been tested by analysing the problem complex of the development and future marketing of GM-ryegrass from the perspective of a company who has an influential international position in the field of ryegrass breeding. Another perspective could have been a societal perspective focusing conflict scenarios between different interested and affected parties of the society.

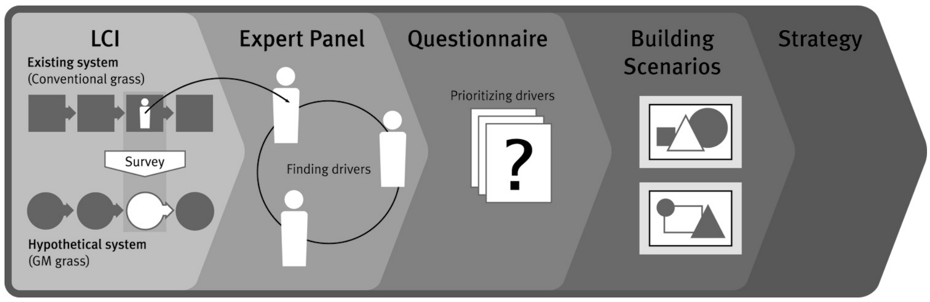

Figure 4. The methodological framework and hierarchic flow used for the analysis of the GM-ryegrass Life Cycle Inventory.

5.1 Life Cycle Inventory

The inventory process seems simple enough in principle. In practice, it is subject to a number of practical and methodological problems.

Agricultural production systems are highly complex and the necessary information to describe the system adequately is scattered across numerous persons, disciplines and institutions.

Defining system boundaries is a subjective choice taken as one of the first steps of the LCI. System boundaries comprises:

- life cycle boundaries, i.e. stream cut-offs, principal parts, leading element
- temporal boundaries, i.e. time horizons
- geographical boundaries, i.e. geographic area, recipients
- impact assessment boundaries, i.e. limitations concerning data, methods etc.

The use of ryegrass in grassland agriculture is a complex question with a considerable amount of possibilities to maximise yield depending on:

- <u>Soil</u>: clay soil; sandy soil; irrigated sandy soil etc.
- <u>Utilisation</u>: grazing; mowing for hay; mowing for silage; seed production; whole crop production etc.

- Sowing: catch crop in spring crops (e.g. barley) as cover plants with or without clover (*Trifolium* spp.); pure breeding with or without clover (*Trifolium* spp.) etc.
- Field system: rotation principles (crops, cattle); pest management, fertilisation etc.

In this feasibility-study we have chosen one specific grass field system producing ryegrass for forage for dairy cattle, see Table 2, and Figure 5 (Landbrugets Rådgivningscenter 1998, Nielsen 1999, Kristensen 1994).

Table 2. Description of grass field system boundaries.

General	The cattle are brought in for milking and foddering in the evening and released to the field in the morning after foddering and milking. The grass area is cut twice during summer when needed.
Soil	Irrigated sandy soil. Irrigation: 120 mm year^{-1}
Fertilisers	150 kg N ha^{-1}
Utilisation	Grazing, cutting. Forage for dairy cattle. Optimal fodder level: 17,9 FE*) + 10% supplementary grains day^{-1} cow^{-1}. Expected yield from the pasture: 7500 FE ha^{-1}
Sowing	Mixed pasture (ryegrass with 30-50%) clover. Ryegrass and clover is sown as catch crop in spring crop (barley). Plant material: *Lolium perenne L.* (Clone F4), Trifoleum repens L.
Field system	Intensive production: 0.25 ha cow^{-1} year^{-1} of cultivated grass in a barley with catch crop grass/clover for grazing field system of mixed pasture from early May to early October. Rotation: The paddocks are rotated in such a way that 80% is utilised for grazing and 20% is utilised for cutting (regulated large paddock. Animal density. 6-7 cows ha^{-1} (farms with milk quotas will have a priority for high animal density giving a high milk production per ha).

*) Food Unit (in Danish: Foder Enhed)

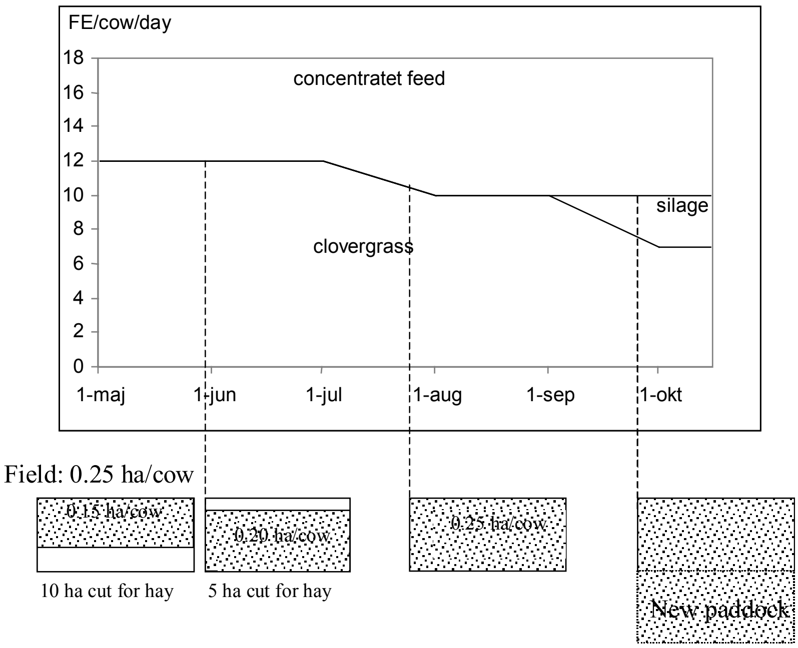

Figure 5. Time dependent FE value of a mixed pasture during a grazing season. The field at the bottom indicates rotation and % of the area utilised for grazing (dotted space) and cutting (white space) (Nielsen 1999).

The basis for the LCI is the determination of the principal parts or leading elements of the system and the starting and ending point of the life cycle. For a biological system the starting and ending point of the life cycle have to be defined arbitrary as a biological system in principal has no start or end. Furthermore, the leading element can be chosen in several ways.

In this study the grass field has been determined to be the leading element in the life cycle. The starting point is a field immediately after manure spreading in autumn and the ending point is the field 2½ years later after reploughing in spring with grass remaining, see *Figure 6*.

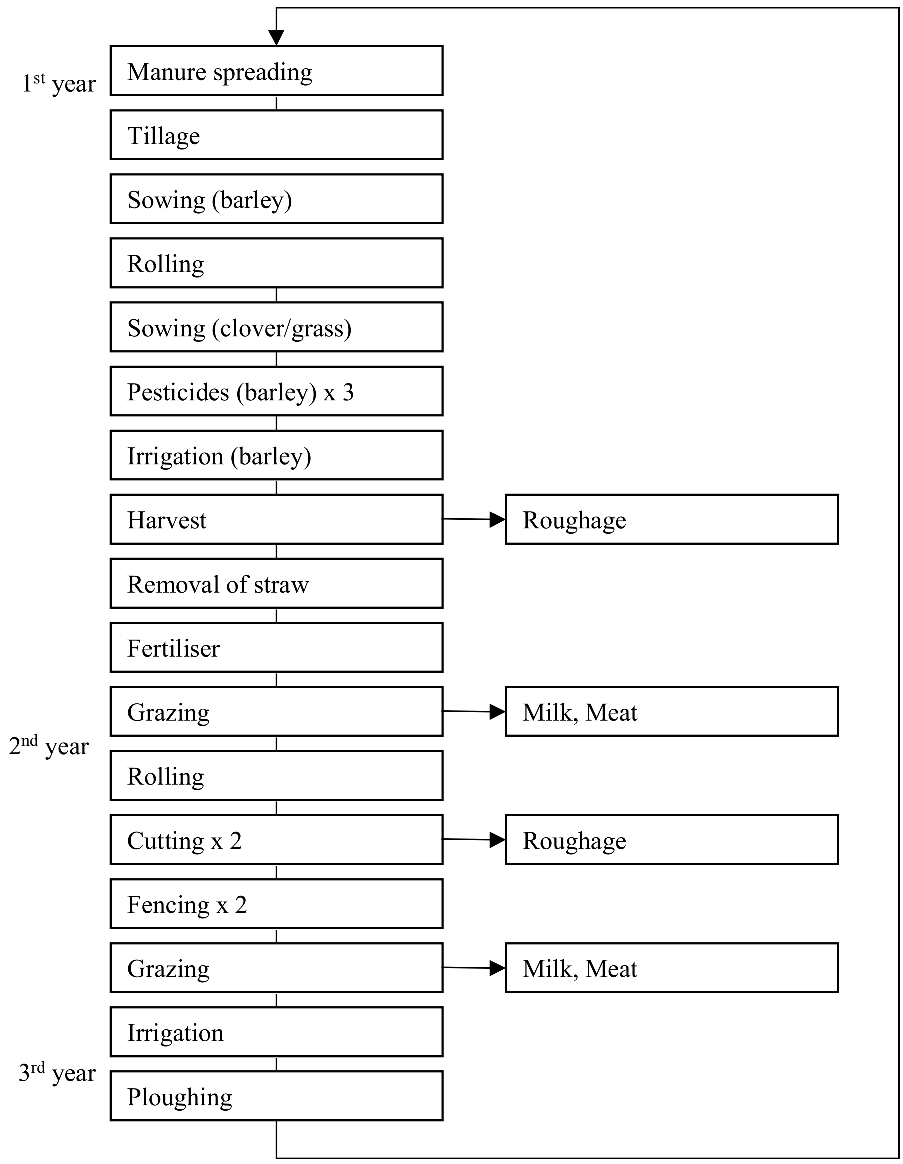

Figure 6. Conventional grass field life cycle

The life cycle inventory was carried out for the conventional ryegrass system. Enclosure A gives a description of each step in the life cycle together with an overview of the related environmental implications. Based on this LCI a qualitative discussion was made of what would happen in the different steps of the LCI, if the system was a genetic modified ryegrass system.

The following key issues were identified:
- The number of steps in the LCI may be reduced for a GM-ryegrass system.
- Improved utilisation of the area.
- Reduced use of fertilisers as grass requires less than roughage.
- Few changes in field management.
- Improved / altered nutritional value.

5.2 Expert panels and drivers

Generally speaking, expert panels are selected representatives of key constituencies and persons with substantive knowledge in the field of question. These experts need to have the ability to extend their substantive knowledge into the uncertainties of the future, and they have to be imaginative. Identifying the right experts is crucial if the analysis is to be a success, and in this study the LCI was an adequate tool to identify an initial pool of expert or network from which panelist could be chosen. In order to discuss the key issues identified in the LCI the following experts were designated to participate in the panel:
- scientists from the company, DLF-Trifolium
- scientists from the field of ecological risk assessment
- scientists from the field of technology risk assessment
- scientists from the field of technology foresight
- representative from the authorities
- representative from the national centre of plant cultivation.

Scenarios consider the wider implications of future decisions, such as changes in the structure of industry sectors, political decisions, consumer acceptance, substitute technologies and so on. To build scenarios (see section 5.4) it is necessary to find major drivers. This was done by letting the expert panel brainstorm over a trigger question related to distinctive time phases from development to marketing of the GM-ryegrass. For example, a trigger question in the marketing phase could be: "Which issues can make the marketing of the GM-ryegrass a success or a failure?"

Initially a time line was constructed naming the phases from idea to fulfilment of a future company success goal. Simultaneously key actors in each phase were identified. The phases considered were: a) development from idea to enclosed experiments, b) enclosed experiments, c) field experiments, ecological risk assessment, d) commercial scale release and e) marketing.

A brainstorming session identified the drivers and key trends of the scenarios by use of the so-called STEEPV approach (Loveridge 1996). This approach can be characterised as a checklist focusing the following themes: Social, Technological, Economic, Ecological, Political and Value. However all six themes of the STEEPV approach may not necessarily be present or have a significant impact in all phases.

The brainstorm revealed a number of drivers and among these the panel chose those that were believed to have the largest impact on the future direction of the GM technology. The identified drivers and key actors are listed in Table 3, where the drivers have been divided into inevitable and predetermined drivers and uncertain drivers. The intervals of the uncertain drivers are essential in the next step to find trends and structural mechanisms for the identification of scenario extremes.

From the column (Table 3) describing the uncertain drivers related to technology development strategy, the expert panel considered the following important:

- economy (corporate research and development)
- public acceptance of GM crops
- farmer acceptance of the product
- international relations (demands and requirements from the national and international authorities and institutions).

Table 3. Listing of drivers and key actors in different phases of developing GM-ryegrass.

Phase	**Key actors**	**Inevitable or predetermined driver**	**Uncertain driver**
Idea → enclosed experiments	Research institutes Company (Agro Industry) (Authorities)	Information Communication Know-how Trust Network Team work	Competitors Policy Economy - time - collaboration - spin of - external know-how - human resources - new technology
Enclosed experiments	Company Authorities	Proof of concept Approval - collaboration - trust - knowledge of authorities - information - communication - the law	Plant material (tests)
Experimental release	Company Authorities (Consumers)	Information Communication. - firm ethics Approval - tests Genetic stability Ethics Knowledge Tests	Plant material Ethics Risk assessment Public feeling - monopoly - media - policy - interest groups - organic farming - utility value
Commercial scale release	Company Authorities Politicians Consumers Farmers organisations	Approval Information Communication - firm ethics Genetic stability Utility value Knowledge	Ethics Risk assessment Public feeling Inclusion on variety list EU - hidden agenda - new directives Political opposition
Marketing	Company Authorities Consumers Farmers	Monitoring Alternative products Market effects Facts Image - press - media Politicians	Farmer accept Communication Economy Internat. relations Unpredicted effects Public acceptance - interest groups

The drivers related to corporate research and development covers aspects as:
- competitors
- keeping the time schedule for the research work, especially identification of genes
- keeping human resources and qualification within the company
- availability of external know-how.

The drivers related to public acceptance covers aspects as:
- public perception of risks
- different viewpoint on criteria for risk acceptance
- social risk aversion (Yardley et al 1997)
- information and communication of risks
- uncertainties related to future risks of GM crops
- public distrust with respect to authorities and industries ability to conduct a competent and comprehensive risk management to avoid introduction of new health and environmental hazards, e.g. the experiences gained from the BSE epidemic case in the UK (Marchi & Ravetz 1999, Powell & Leiss 1997).

The drivers related to farmers acceptance covers aspects as:
- influence of consumers attitude to GM crops in food and feed on the market
- assessment of the agricultural properties of the crop product by the farmers organisation (inclusion of the crop on the variety list)
- fear for actions by radical interest organisations spoiling the crops at the fields and giving the farmer a bad reputation
- structural changes in agricultural land-use by introduction of GM crops
- conflicts between organic and conventional farming.

The drivers related to requirements and demands from authorities and institutions covers aspects as:
- tighten up the legislative requirements for assessment and approval of GM crops
- increased demands for environments selected for production of GM crops
- increased demands about public health and welfare from consumer organisations and institutes (Forbrugerstyrelsen 1998)..

5.3 Questionnaire

The drivers (twenty-six drivers) were incorporated in a questionnaire and then evaluated in a larger forum of Danish experts and stakeholders (31 out of 49 respondents returned the questionnaire). The questionnaire (in Danish) can be found in enclosure B. The respondents were asked to evaluate each drivers influence on the future demand of GM grass and how certain the outcomes would be in the categories: (A) corporate research and development, (B) public acceptance, (C) farmers acceptance, and (D) marketing of GM crops. Furthermore, the questionnaire asked 3 principal questions for each driving factor: (1) the influence the driving factor will have on the future direction (2) probability that the driving factor will be an imperative factor in the future, and (3) self evaluation (expert, knowledgeable, familiar) of expertise in the category of drivers.

To prioritize a given driver (D_J) by *importance* for the future direction (type 1 questions) we used a method described by Dransfeld et al. (2000). The method use Bayes formula taking into account the different levels of expertise (type 3 questions), which allows the data to be expressed in terms of probabilities. Bayes formula allows us to update an initially presumption of D_J by asking the respondents about how important they believe D_J will be for the future trend with respect to the GM grass. The initially presumption here is that the probability is fifty-fifty ($P(D) = P(\overline{D}) = 0.5$) since we do not know whether the relative importance of D_J is high or low.

To account for the different levels of expertise we categorize the respondents in I categories (Table 4) and assume that each expert in a category has the same two unknown conditional probabilities p_I and q_I. p_I is the probability that the respondent guess or judge the right priority (i.e. stating that the importance of D_J is high and it turns out to be low) whereas q_I is the probability of the respondent to guess or judge an incorrect priority to D_J. These conditional probabilities will differ respondent categories, since we anticipate that an expert has a higher probability of guessing the correct priority to D_J (Table 4).

Table 4. Respondent probabilities of giving the right priority of D_J *right or wrong.* p_I *is the probability that the respondent give the right priority to a given driver* D_J*, and* q_I *is the probability that the respondent give the incorrect priority to* D_J.

Expert self rated category (*I*)	Expert	Knowledgeable	Familiar
$p_I = P(Y \mid D)$	0,625	0,6	0,5
$q_I = P(Y \mid \overline{D})$	0,4	0,425	0,5

Suppose that our panel exists of n_I respondents from the three categories of expertise (Table 1) who returned their questionnaires, and that y_I of these said that the importance of D_J is high. Assuming that the respondents made their decisions independently, then the probability of *data* given D_J is:

$P(data \mid D)$

Introducing this in Bayes formula we get:

$$P(D \mid data) = \frac{P(data \mid D) \cdot P(D)}{P(data \mid D) \cdot P(D) + P(data \mid \overline{D}) \cdot P(\overline{D})},$$

and assuming that $P(D) = P(\overline{D}) = 0.5$ (Dransfeld et al,. 2000 for details)

$$P(D \mid data) = \frac{P(data \mid D)}{P(data \mid D) + P(data \mid \overline{D})},$$

where $P(data \mid D) = \prod_{I=A}^{C} p_I^{y_I} (1 - p_I)^{n_I - y_I}$ and

$$P(data \mid \overline{D}) = \prod_{I=A}^{C} \overline{q}_I^{\,y_I} (1 - \overline{q}_I)^{n_I - y_I},$$

It is important to note that we do not use the probabilities as a prediction of the future direction but as a ranking of the drivers according to importance based on the judgement by the respondents (Table 5).

The *uncertainty* of *D*, indicate to which degree the respondentss agree about the future trend of a given *D*. If the respondents agree about the future trend the uncertainty is low even though the trend is making the decisions more difficult. The uncertainty was estimated by asking what the future trend would be and analysing if they disagreed or not. The way the questionnaire was set up allowed for two types of disagreement:

a) disagreement inside the respondent group
b) disagreement between the respondent groups

If either a or b occurred either alone or together the uncertainty was rated high. If all respondents agreed the uncertainty was rated low.

The twenty-six drivers can now be arranged in two dimensions namely according to importance and according to uncertainty (Figure 7).

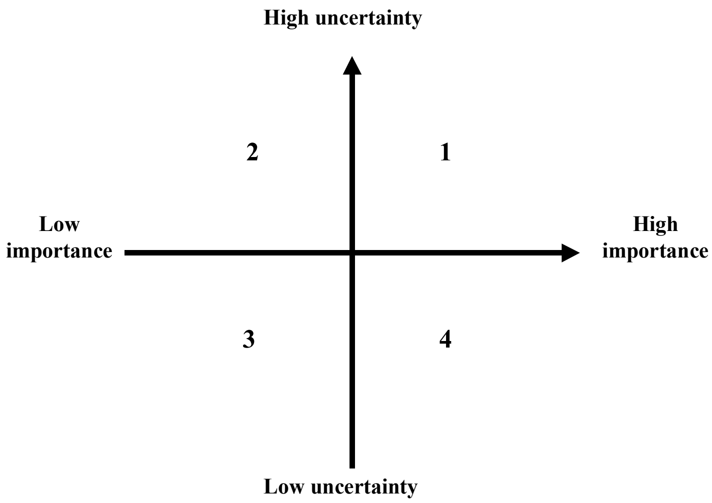

Figure 7. Matrix in which the drivers can be sorted with respect to importance and uncertainty.

Thus, we end up with a simple matrix of four quadrants, where each driver can be placed according to importance and uncertainty, high or low. Based on the work of David Mercer (1995) each quadrant can be described as follows:

- 1st Quadrant: Drivers with high importance and high uncertainty - the variable and most important drivers which have a direct influence on the future direction but the outcome is uncertain
- 2nd Quadrant: Low importance and high uncertainty - the wild cards because they are uncertain but immediate regarded as not so important. It is possible they can move into the 1st quadrant.
- 3rd Quadrant: Low importance and low uncertainty - context shapers that influence the future direction only indirectly.
- 4th Quadrant: High importance and low uncertainty - the important trends that are predictable and are present in all scenarios.

Table 5 summarises the results of the questionnaire. In the following we will concentrate on the important drivers i.e. the drivers that end up in the 1st quadrant. These drivers are considered the most interesting because they have direct influence on the future direction, but are difficult to predict and manage.

With this procedure 4 drivers appear in the important 1st quadrant: Two from the A group (Drivers that influence the technical development of GM crops) and two from the B group (Drivers that influence on the public acceptance).

Table 5. The twenty-six drivers identified by an expert panel and subsequently ranked with respect to importance and uncertainty by a broader pool of stakeholders via a questionnaire. Column Q denotes the quadrant where the driver is placed in the matrix .

	Impor-tance	Uncer-tainty	Q
A) Drivers that influence the technical development of GM crops			
A1. Being first on the market	high	high	1
A2. High R & D cost of GM crops	high	low	4
A3. Having the required biomolecular know how in house	low	high	2
A4. Having an efficient professional network	high	high	1
A5. Threads from new technologies	low	low	3
A6. Investors attraction of controversial technologies	low	high	2
A7. Investors sensitivity towards disparage regarding GMO's	low	high	2
A8. Having a dialog with the authorities	low	low	3
B) Drivers that influence on the public acceptance			
B1. Disagreement on risk between the public and the experts	high	low	4
B2. Public participation in regulation	high	high	1
B3. Public knowledge	low	high	2
B4. Public trust in authorities	high	low	4
B5. Utility value	high	high	1
B6. Formation of monopoly by multinational biotech companies	high	low	4
B7. Well defined EU policy on GMOs	high	low	4
C) Drivers that influence on the agricultural society acceptance			
C1. Having a good image	high	low	4
C2. Technical approval of the GM crop by the agricultural assoc.	high	low	4
C3. Altered cultivation procedures and area use due to GM crops	low	high	2
C4. Contermination of organic crops by GM crops	low	high	2
C5. Authorial regulations and provisional orders	low	high	2
C6. Reduced production costs	high	low	4
C7. Influence of NGO's	low	low	3
D) Drivers related to the market for GM crops			
D1. National and cultural differences in attitude towards GMO's	low	high	2
D2. Existence of alternatives to GM crops	low	low	3
D3. Profitable but risky market	low	high	2
D4. Having a global market	low	high	2

To be the first to market the GM-ryegrass is considered important by most of the respondents, however they do disagree on whether the company will in fact be first on the market (A1, Table 5). It is not surprising that first to market is considered important to allow for a monopolistic time period, which probably is necessary to pay back the resources that have been invested in the project. Keep in mind that high R & D cost was regarded an important and inevitable factor (A2, Table 5). All though the question was focused on the existence of competitors the high uncertainty may arise from an expected resistance from the public towards GM crops (this is discussed later), which may baffle the marketing all together. In relation to this but in a different context the respondents was also asked about the importance of being in a market with high risk and a potential of a very high profit (C3, Table 5). The majority of the respondents (quite few considered them selves as expert in matters of marketing GM products) did not rate this as very important, however, they were very ambivalent to whether the GM-ryegrass in fact will give a significant profit to the company.

Networking also was rated as very important but the respondents did not agree if an efficient network could be established. The reason why it is necessary with a network has probably to do with the complex knowledge that is required for this type of entrepreneurship. In this light it is strange the respondents did not believe that it was necessary to have the required biomolecular know-how in house (A3, Table 5).

The drivers that influence on the public acceptance public participation in regulation and utility value appeared in the important 1st quadrant. The incorporated opinion expressed by the respondents that public participation in regulation is necessary and important (B2, Table 1) probably reflects a concern about the disagreement between the public and the experts on risk regarding GM technology (B1, Table 5), which lately have been documented in Eurobarometer No. 52.1. On the other hand there is uncertainty to whether a dialog can be established that could break down the disparity. The other important driver with respect to public acceptance towards GM crops is utility value, where the incorporated respondent opinion express uncertainty whether it can be achieved in a near future.

5.4 Building scenarios

Scenario analyses has previously been used in exploring options for future crop production (Rabbinge & Oijen, 1997). It considers the wider implications of future decisions such as changes in the structure of the industry sectors, political decisions, consumer acceptance, substitute technologies etc. The objective is to find solutions that perform well under all scenarios.

It is important to have identified a number of scenarios in order to give the decision makers the opportunity to monitor trends and to be prepared for alternative developments in technology, marked and legislation. By using the uncertainty interval of the uncertain drivers (Table 3) several scenarios were constructed and two examples are presented in Table 6, which are further described in Table 7 and Table 8.

The scenarios can be utilised as tools for organising one's perceptions about alternative future environments in which one's decisions might be played out. By using the scenarios as guiding points the company can use the inevitable or predetermined drivers already identified to manoeuvre in changing and unstable political environment towards a plausible future scenario. Moreover, in changing and unstable political environment it is important to have identified several scenarios giving the decision-makers the opportunity to monitor trends and be prepared for alternative developments in the market. The number of scenarios normally used in scenario analysis can vary from two up to seven, depending on the objective. The more scenarios the more over-view is necessary.

When discussing the implementation of GM crops from a company perspective, a trend scenario, which describes the development from the present situation emphasising certain trends is the most useful. From a more superior perspective concerning the acceptance of GM crops among the consumer the combined industry must collaborate with the authorities in developing threat and conflict scenarios (worst case scenarios), which can elaborate possible conflicts and the causes, and suggest countermeasures. In this connection it should be remarked that Schnaars (1986) has suggested four different approaches that can be adopted when designing strategy with multiple scenarios: (1) a robust strategy that performs well over the full range of scenarios considered, (2) a flexible strategy that keep options open for as long as possible and consider the cost of postponing a decision, (3) a multiple coverage strategy that simultaneously pursue multiple strategies using extensive resources until the future becomes clear, and (4) a gambling strategy where the strategy is selected by gambling on the development of other futures in which it produces more than proportional returns.

The two constructed scenarios are:
- Scenario 1: Sensational driven media coverage of actions by NGO's against GM crops (Table 7).
- Scenario 2: EU demands severe and expensive measures for producing GM seeds (Table 8).

Table 6. Uncertain intervals of the uncertain drivers. The numbers exemplifies two different scenarios.

Drivers that influence the technical development of GM crops			
A1: First on the market (Q1)	*Come first*	… **1,2** ……………….....…	*Come late*
A4: Network (Q1)	*Present*	… **1** ………..……… **2**	*Absent*
Drivers that influence on the public acceptance			
B2: Public participation (Q1)	*High*	………… **1** ……..… **2** …....	*Low*
B5: Utility value (Q1)	*High*	… **2** ……………..… **1** …....	*Low*

Table 7. Scenario 1: Doubt about the utility value

The company has successfully developed a GM-ryegrass, however, the ryegrass stands weak in the public opinion as it mainly is developed as a grass with increased nutritional value, and thus is seen beneficial only to the farmers in reducing their cost to supplemental fodder. Therefore the investors are nervous and there is a risk that they will move out if the public hesitance prevail.
A possible counteraction by the company could be to run reliable trails that prove the GM-ryegrass to have public values e.g. that it is environmental benign and has advantage compared to conventional grass. If the company at the same time actively and transparently supports research in risk assessment there may be a good chance to convince the public that the GM-ryegrass proposes significant advantages.

Table 8. ***S****cenario 2: Getting the network to work*

To secure progress in the project it is necessary to import knowledge outside the company using a comprehensive network. However, it is difficult to communicate in a network with out revealing competitive advantages and trade secrets of the company.
Possible counteraction could be that the company gave access to their knowledge (open source) to out-site research organisations while protecting key technologies and methodologies through intellectual property rights. This would, attract laboratories who could contribute the main project with knew knowledge and ideas and join hands on in developing new methodologies.

The most important outcomes of the scenarios are the identification of the alternative futures and realising the uncertainty these imply and for the stakeholders to develop the strategies to address these. The process it-self is very motivational because it provides for a dialectical debate among the experts and stakeholders that can lead to alternative solutions.

6 Discussion

The procedure described here, suggesting a method where complex problems can be structured and discussed cross-disciplinary, is a fruitful way of finding technology drivers, however, the crucial point is to nominate members to expert panels who can use their imagination to expand their knowledge to judge about the future. Regarding the questionnaire and the ranking of the drivers with respect to importance and uncertainty, Denmark has a size where it is relative easy to find the experts to whom the questionnaire can be addressed. In a larger context it may be necessary with a co-nomination procedure (Nedeva et al., 1996) wherein the initial group of experts is asked to identify further individuals to ensure all issues are covered. It may be argued that the type of questionnaire used reflects an expert opinion and not the general public, however, the experts did find themselves in the position of educated laypersons answering many of the questions, which may have given them a more humble attitude. Finally, the method of using probabilistic presentation of subjective judgement provides a clear criterion for ranking importance and clearly separated the drivers. Where the separation between high and low importance and uncertainty is placed is up to the individual case and depends on how many drivers are necessary or manageable to perform a sustainable long term planning, for example in the process of building scenarios. Ranking uncertainty we found that disagreement in the answers was an adequate criterion to reflect uncertainty, where the crucial point is the formulation of the question.

The LCI gave an overview of the problem complex and was sufficient in organising the grass field system and in defining the system boundaries. The main problem was to find boundaries that limited the complexity of the system without loosing the holistic perspective and sufficient information to compose expert panels and define the baseline for future scenarios. Apart from ecological consequence assessment, there are needs to develop interdisciplinary LCI tools that systematically can organise the problem complex implicated by the introduction of GM crops in agricultural systems. LCI has been shown to be a supporting tool for systems modelling and it provides a basis to TF mapping and scanning, facilitating the identification of parties and experts needed to perform an interdisciplinary analysis. This exercise stresses that it is the process as well as the results of the analysis that can support strategic and regulatory decision making. Moreover, placing experts and involved parties around the same table seems to create a common understanding leading to alternative solutions.

Finally, the study revealed the societal necessity to reach a consensus about coverage and application of risk assessment on GM crop technology. The central issues concerning risk assessment, risk acceptance and risk management related to development and raising of GM crops are areas that needs further investigations. Special emphasis shall be laid on how to integrate social theories and technological risks in technology foresight studies.

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ENCLOSURE A

Description of the life cycle inventory for conventional ryegrass

The life cycle of the conventional ryegrass system is shown in Figure 6. The following gives a description of each step in the life cycle together with an overview of the related environmental implications.

Manure spreading

When the cows are tied over night and during winter manure is collected for later application to the fields. Manure is often used on the cover crop rather on the grass pasture where it will increase the risk of contaminate the cows with lungworm (Dictyocaulus viviparus). However, too high N application will reduce the percentage of clover in the undersown grass/clover. The objective is to increase the yield. The machinery requirement is a 16 m drag hose and the man power needed is 0.75 hours ha^{-1}.

<u>Environmental implication</u>

- Affect: Emission to soil and air. Emission from tractor (see rolling).
- Spreading: Leaching and atmospheric.
- Load: Nutrient excesses N, P, CH_4 and N_2O from manure management.
- Consequences:
  - Percolation of N will lead to eutrophication of coastal water resources (N). Soil erosion will remove P from the field and deposit this nutrient in streams and lakes leading to eutrophication of these. Eutrophication due to P and N loss from the field will deplete the fishing stock and reduce the amenities. Moreover, distribution of manure will cause emission of nitrate to the atmosphere and finally deposit in the sea.
  - During storage CH_4 will be produced due to decomposition casing an increase in greenhouse gasses (se roller). During storage some of the manure nitrogen is converted to N_2O which among others also is a green house gas (see rolling).

Tillage

The pasture can be tillage in the autumn or in the spring depending on the following crop. However nitrogen loss will be considerably higher if tilled in autumn. To reduce nitrogen loss the pasture should be tillage in spring and followed by a crop that can catch the released nitrogen (Djuhuus & Olesen, 1997). The objective is to establish new crop. The machinery requirement is a 6 m harrow and the man power needed 0.29 hours ha^{-1}.

<u>Environmental implication</u>

- Affect: Emission of N. Emission from tractor (see rolling 1st year).
- Spreading: Leaching. Atmospheric.
- Load: Eutrophication. CO_2 , NO_2, SO_2, PAH (tractor)
- Consequences: Se manure spreading with regard to N. Se rolling with regard to tractor.

Sowing (springbarley)

Barley must be sown as soon as the soil is ready and man power required is 0.37 29 hours ha^{-1} using a 6 m seed drill.

<u>Environmental implication</u>

- Affect: Emission of N. Emission from tractor (see rolling 1st year).
- Load: Eutrophication. CO_2 , NO_2, SO_2, PAH (tractor)
- Consequences (see rolling with regard to tractor).

Rolling - 1st year

The ideal establishing conditions for grass is a fine structured soil that is moist nearly to the surface. The sowing depth should be no more than 1-2 cm to get an optimal germination. By rolling a dense and even surface is achieved which will preserve moist and make it easier to control sowing depth and later cutting for hay. Moreover an even field surface will ease the load on the machinery. The objective is to preserve moisture in and to get the surface even due to shallow sowing depth. The machinery requirement is a 6 m Cambridge roller and the man power needed is 0.32 hours ha^{-1}.

Environmental implication

- Affect: Emission from tractor as CO_2 , NO_x, SO_x, PAH.
- Spreading: Atmospheric.
- Load: CO_2 , NO_2, SO_2, PAH.
- Consequences:
  - CO_2: Increasing glasshouse effect leading to global heating.
  - SO_2: The acid rain causes surface water acidification and damages trees at high elevations. Air concentrations degrade visibility and pose a risk to public health. In addition, acid rain accelerates the decay of building materials and paints. High levels of SO_2 have been proven to cause or aggravate various types of lung disorders. These problems, which affect a person's ability to breathe, have led to both increase sickness and deaths.
  - NO_2: Indirectly increasing glasshouse effect, acid rain, polluting of drinking water, increasing frequency of respiratory and cardiac sicknesses, formation of photochemical smog. They are damaging to human health, cause damage to plants, buildings and monuments and are an essential contributor to the excessive formation of ozone and other health-endangering oxidants during the summer heat periods.
  - PAH: Anticipated to be carcinogens and toxic to animals.

Sowing - 1st year

Grass and clover is mixed and the sowing depth is shallow, hence there is a risk for desiccation. The machinery requirement is a 6 m sowing machine and the man power needed is 0.37 hours ha^{-1}.

Environmental implication

- Affect: Emission from tractor (see rolling).

Pesticide - 1st year

Pesticides enclose herbicides, fungicides and insecticides and are applied to the field prophylactic or when needed. The purpose is to prevent yield loss due too competition from weed and sickness in the crop. The machinery requirement is a 24 m boom and a 36 l tank and the man power needed: 0.21 hours ha^{-1}.

Environmental implication

- Affect: Directly and indirectly emission to soil. Emission from tractor (see rolling).
- Spreading: Leaching.
- Load: Residues.
- Consequences:

- Pesticide use has caused serious environmental problems, polluting soil and water and causing health hazards for humans and animals. Pesticides can enter ground water both directly and indirectly. Direct contamination may occur from pesticide spills close to a well, back-siphoning during spray tank filling, or improper storage and disposal of pesticides. Indirect contamination can occur when pesticides move down through the soil (percolation) into the ground water. Humans can also be exposed to pesticide residues left on agricultural food products.
- When wildlife habitats on a farm are lacking or of poor value, wildlife populations decline due to lack of food and cover (reduced biodiversity).
- Pesticide resistance may develop in and create problems in controlling noxious weeds and insects and in turn create a need for stronger and potential more toxic herbicides.

Irrigation (barley) - 1st year

During dry periods it may be necessary to irrigate, especially on sandy soils. The objective is to prevent desiccation of grass and barley and thus yield loss. The externalities related to the activity is depletion of drinking water resources and desiccation of streams. The machinery requirements is a stationary machine with rolling up hose and the man power needed is 0.33 hours ha^{-1}.

<u>Environmental implication</u>

- Affect: Depletion of streams and lakes and drinking water resources.
- Load: Desiccation fresh water resources.
- Consequences: If a well supplies the irrigation water intensive use of water will lover the water table and desiccate more shallow wells. If a stream or lake is used the there is a risk for drainage of the belonging water system all ready desiccated due to lack of rain leading to wildlife and amenities loss.

Harvest

Spring barley is normally harvested in the first half of august. Timing is crucial since too early harvest can cause problems with releasing the awn. Too late harvest can cause problems with germination in the spike. Man power needed is 0.33 hours ha^{-1} using harvest width of 6 m.

Removal of straw after harvest - 1st year

After the cover crop has been harvested the pasture has to be clean from straws allowing light and air to reach the grass. The objectives are to collect roughage and remove of straw allowing light to reach the grass. The machinery requirement is a tractor and the estimated man power needed 0.1 hours ha^{-1}.

<u>Environmental implication</u>

- Affect: Emission from tractors (see roller) (harvester is not counted in as the activity belongs to gathering of barley.

Fertiliser - 1st year

Perennial ryegrass is very responsive to N, but high application of N will decrease the amount of clover. Fertiliser is used rather than manure to prevent smearing of the grass and infection of lungworm (Dictyocaulus viviparus). The objectives are to ensure grass adequate amounts of nutrients and to increase crude protein content of grass. The machinery requirement is a 20 m spreading wagon and the man power needed is 0.2 hours ha^{-1}.

Environmental implication

- Affect: Nitrogen mission to soil and air (se manure application). Emission from tractor (see rolling).
- Spreading: Leaching and atmospheric.
- Consequences: See fertilisation with manure regarding N.

Grazing - 1st year

When the grass is mature in late September the herd is allowed access to the new paddock. This is the cheapest way to collect roughage for foddering. The activities of the herd give rise to emissions of CH_4 and N_2O from the enteric fermentation. Especially ruminants are a large source compared to other animals due to their ability to digest cellulose. The amount of CH_4 that is released depends on the quality of the feed and the energy expenditure of the animal. The objective of the activity is to provide roughage.

Environmental implication

- Affect: Nitrogen and phosphorus emission to soil and air (se manure application). CH_4 and N_2O emission from the cow.
- Spreading: Leaching and atmospheric.
- Consequences: N and P: Se manure spreading. CO_2 and CH_4 (see rolling).

Rolling - 2nd year

When the field can carry the tractor in the spring it is rolled mainly to get rid of stones. The objective is to get the field even ensuring even cutting and reduce load on machinery. The machinery requirement is a 6 m Cambridge roller and the man power needed is 0.32 hours ha^{-1}.

Environmental implication

- Affect: Emission from tractor (see rolling - 1st year)

Grazing - 2nd year

The cows are released in the spring and brought in by night for milking and supplementary foddering. The objective is to provide roughage.

Environmental implication

- Affect: Nitrogen and phosphorus emission to soil and air (se manure application). CH_4 and N_2O emission from the cow (see grazing above).

Irrigation - 2nd year

See irrigation 1st year.

Cutting -1st + 2nd year

Gathering of excess grass fore storage (winter feed). It also works as a buffer where the area can be reduced and used for grazing if the grass quality is low. It also reduces the risk of infection by lungworm. The objective is to provide roughage for winter feed. The machinery requirement is big bales and the man power needed is 0.67 hours ha^{-1}.

Environmental implication
- Affect: Emission from tractor (see rolling).

Reploughing

Plaguing is the most expensive operation, and very variable. The soil should be worked as little as possible to reduce the costs. The man power needed is between 1-2 hours ha^{-1} depending on the material.

Environmental implication (see Tillage).

ENCLOSURE B

Questionnaire

<u>Drivfaktorer der har betydning for virksomhedens udvikling af GM afgrøder</u> **Hvad er dit kendskab til dette område?** ❑Jeg arbejder inden for området ❑Jeg har kendskab til området ❑Jeg er lægmand	meget stor	stor	lille	meget lille	*forstår ikke sp.*
Konkurrenter kan være interesseret i markedet for genteknologiske græs. 1. Hvilken betydning har det, om virksomheden får markedsført GM græs før konkurrenterne?	☐	☐	☐	☐	
2. Hvad er sandsynligheden for at virksomheden bliver den første til at markedsføre GM græs?	☐	☐	☐	☐	
Omkostningerne til at udvikle GM græs kan være meget høje. 1. Hvilken betydning har de økonomiske ressourcer for udvikling af GM græs?	☐	☐	☐	☐	
2. Hvad er sandsynligheden for, at virksomheden vil tilføre projektet ekstra ressourcer, hvis budgettet overskrides?	☐	☐	☐	☐	
Der skal omfattende knowhow til at udvikle GM afgrøder. 1. Hvilken betydning har det, at virksomhedens ansatte selv har al denne knowhow?	☐	☐	☐	☐	
2. Hvad er sandsynligheden for, at ekstern viden og teknologi vil være tilgængelig i det nødvendige omfang?	☐	☐	☐	☐	
Konkurrencen inden for det genteknologiske område er stor, hvilket kan medføre en vis træghed i udveksling af information. 1. Hvilken betydning har det faglige netværk i den kommercielle udvikling af en GM afgrøde?	☐	☐	☐	☐	
2. Hvor sandsynligt er det, at netværket uhindret vil kunne udveksle erfaringer?	☐	☐	☐	☐	
Der udvikles hele tiden mere effektive genteknologiske metoder. 1. Hvilken betydning har det, at der dukker nye teknologier/metoder op, der er mere effektive end dem virksomheden behersker.	☐	☐	☐	☐	
2. Hvad er sandsynligheden for, at der dukker nye teknologier op.	☐	☐	☐	☐	
Muligvis skal der tiltrækkes kapital til virksomheden fra investorer. 1. Hvilken betydning har det for tiltrækning af investorer, at GM afgrøder er et kontroversielt område?	☐	☐	☐	☐	
2. Hvad er sandsynligheden for, at der i fremtiden vil være investorer til genteknologiske produkter?	☐	☐	☐	☐	
Investorerne kan overreagere på negativ omtale af genteknologien. 1. Hvilken betydning har det, at investorerne har en god forståelse for genteknologi.	☐	☐	☐	☐	
2. Hvad er sandsynligheden for, at investorerne kan oplyses tilstrækkeligt om genteknologi?	☐	☐	☐	☐	
Myndighederne kræver omfattende dokumentation for godkendelse af GM afgrøder. 1. Hvilken betydning har virksomhedens forhold til de ansvarlige myndigheder?	☐	☐	☐	☐	
2. Hvad er sandsynligheden for, at myndighederne vil gå i dialog med genteknologiske virksomheder?	☐	☐	☐	☐	
Kommentarer ønskes, da der er tale om et udviklingsprojekt, og vi har begrænsede erfaringer med denne type spørgeskemaer:					

Drivfaktorer, der har betydning for offentlige accept af GM afgrøder. **Hvad er dit kendskab til dette område?** ❑Jeg arbejder inden for området ❑Jeg har kendskab til området ❑Jeg er lægmand	meget stor	stor	lille	meget lille	*forstår ikke sp.*
Ofte er forbrugernes og eksperternes opfattelse af risiko forskellig. 1. Hvilken betydning har det, at eksperterne og borgernes opfattelse af risiko stemmer godt overens?	☐	☐	☐	☐	
2. Hvad er sandsynligheden for at få en bedre overensstemmelse mellem eksperternes og forbrugernes risikoopfattelse?	☐	☐	☐	☐	
Industrien bliver ofte beskyldt for at misinformere. 1. Hvilken betydning har det, at der findes en åben dialog om fordele og risici ved dyrkning af GM afgrøder?	☐	☐	☐	☐	
2. Hvad er sandsynligheden for, at der kan skabes en åben dialog med forbrugerne	☐	☐	☐	☐	
Det hævdes ofte, at forbrugerne er skeptiske over for genteknologi på grund af manglende viden. 1. Hvilken betydning har det for accepten af GM afgrøder, at forbrugerne har viden om genteknologi?	☐	☐	☐	☐	
2. Hvad er sandsynligheden for, at forbrugerne kan få kvalificeret viden om genteknologi til at tage stilling til genprodukter	☐	☐	☐	☐	
På mange områder er forbrugerne blevet mere skeptiske overfor myndighedernes vurderinger af risiko. 1. Hvilken betydning har det, at forbrugerne har tillid til myndighedernes risikovurdering?	☐	☐	☐	☐	
2. Hvad er sandsynligheden for, at myndighederne kan opnå forbrugernes tillid til deres risikovurdering?	☐	☐	☐	☐	
I modsætning til GM afgrøder har medicinal industriens anvendelse af genteknologi ikke mødt stor modstand. 1. Hvilken betydning har det for accepten af GM afgrøder, at forbrugeren kan se en stor nytteværdi?	☐	☐	☐	☐	
2. Hvad er sandsynligheden for, at GM afgrøder kan opnå tilstrækkelig nytteværdi til at forbrugerne vil acceptere dem inden for 5 år?	☐	☐	☐	☐	
Genteknologi er ofte så svært tilgængelig og beskyttet af patenter, så der let kan dannes monopoler. 1. Hvilken betydning har monopoldannelser for accepten af GM afgrøder?	☐	☐	☐	☐	
2. Hvad er sandsynligheden for, at der opstår store monopoler omkring GM afgrøder?	☐	☐	☐	☐	
EU skal også godkende markedsføring af GM afgrøder. 1. Hvilken betydning har det, at EU har en veldefineret politik overfor GM afgrøder?	☐	☐	☐	☐	
2. Hvad er sandsynligheden for, at EU vil få en veldefineret politik overfor GM afgrøder inden for de næste 5 år?	☐	☐	☐	☐	
Kommentar til spørgsmålene:					

Drivfaktorer med betydning for landbrugets accept af GM græs. **Hvad er dit kendskab til dette område?** ❑Jeg arbejder inden for området ❑Jeg har kendskab til området ❑Jeg er lægmand	meget stor	stor	lille	meget lille	*forstår ikke sp.*
Landbruget er ofte blevet kritiseret for brugen af intensive metoder, der fx. skader for miljøet. 1. Hvilken betydning har det for landbrugets image at blive forbundet med genteknologi?	☐	☐	☐	☐	
2. Hvad er sandsynligheden for, at landbrugets image vil blive påvirket, hvis GM afgrøder tages i brug?	☐	☐	☐	☐	
Nye typer og sorter af afgrøder bliver vurderet før de kommer på en "sortsliste" 1. Hvilken betydning har det, at GM græsset kommer på "sortslisten"?	☐	☐	☐	☐	
2. Hvor sandsynligt er det, at GM græsset kommer på "sortslisten" forholdsvis hurtigt efter den er lanceret?	☐	☐	☐	☐	
GM afgrøder kan medføre ændringer i driftsplanlægningen som den kendes i dag. 1. Hvilken betydning kan GM græsset have for arealudnyttelse og landmandens driftsplanlægning?	☐	☐	☐	☐	
2. Hvad er sandsynligheden for, at GM græsset vil ændre arealudnyttelse og driftsplanlægningen væsentligt?	☐	☐	☐	☐	
Det er fremført, at man på sigt ikke kan holde økologiske dyrkningsarealer fri for GM afgrøder. 1. Hvilken betydning har indførelsen af GM græs for den økologiske græsdyrkning?	☐	☐	☐	☐	
2. Hvad er sandsynligheden for, at indførelse af GM græs vil medføre konflikt mellem økologisk og konventionel landbrug?	☐	☐	☐	☐	
Indførelsen af GM afgrøder afstedkommer en række lovmæssige krav og betingelser fra myndighederne. 1. Hvilken betydning har det, at de lovmæssige krav og betingelser er gennemskuelige for landbrugets accept?	☐	☐	☐	☐	
2. Hvad er sandsynligheden for, at myndighedernes krav kan blive en barriere for ibrugtagning af GM afgrøder?	☐	☐	☐	☐	
GM græsset kan reducere omkostningerne i husdyrproduktion. 1. Hvilken betydning har det for landbrugets accept af GM græsset, at det kan reducere produktionsomkostningerne?	☐	☐	☐	☐	
2. Hvad er sandsynligheden for, at landbruget vil tage GM afgrøder i brug for at klare sig i den internationale konkurrence?	☐	☐	☐	☐	
Interesseorganisationer prøver at påvirke myndigheder og politikere. 1. Hvilken betydning har interesseorganisationernes indflydelse for den danske politik overfor GM afgrøder?	☐	☐	☐	☐	
2. Hvad er sandsynligheden for, at politikerne og myndighederne kan påvirkes til ugunst for GM afgrøder?	☐	☐	☐	☐	
Kommentar til spørgsmålene:					

Drivfaktorer relateret til markedet for GM græs **Hvad er dit kendskab til dette område?** ❑Jeg arbejder inden for området ❑Jeg har kendskab til området ❑Jeg er lægmand	meget stor	stor	lille	meget lille	*forstår ikke sp.*
Nogle lande er meget skeptiske overfor GM afgrøder, mens andre lande er mere positive. 1. Hvilken betydning har dette for markedsføringen af GM afgrøder?	☐	☐	☐	☐	
2. Hvad er sandsynligheden for, at der vil ske en udjævning af disse nationale holdningsforskelle?	☐	☐	☐	☐	
GM afgrøder besidder ofte egenskaber, som er vanskelige at fremdrive ved traditionel forædling. 1. Hvilken betydning har det, hvis kvaliteter der modsvare GM afgrøders frembringes ved traditionel forædling (ikke mutations forædling)?	☐	☐	☐	☐	
2. Hvad er sandsynligheden for, at man kan frembringe disse GM kvaliteter ved traditionel forædling?	☐	☐	☐	☐	
Omkostningerne ved udvikling af GM afgrøder er betydelige. 1. Hvilken betydning har det, at investeringer i GM græsset har en kort tilbagebetalings tid efter markedsføring?	☐	☐	☐	☐	
2. Hvad er sandsynligheden for, at GM græsset vil give et solidt afkast til virksomheden?	☐	☐	☐	☐	
Forskellige nationale godkendelses krav for GM afgrøder kan betyde, at nogle markeder er meget svære at trænge in på. 1. Hvilken betydning har det for virksomheden om GM græsset kan markedsføres globalt?	☐	☐	☐	☐	
2. Hvad er sandsynligheden for, at GM græsset kan markedsføres globalt?	☐	☐	☐	☐	
Kommentar til spørgsmålene:					

Skemaet er indsendt af:

Navn:
Organisation:
Adresse:
Tlf.:
E-mail:

Dine svar til denne undersøgelse vil blive behandlet fortroligt.

Kommentarer ønskes, da der er tale om et udviklingsprojekt, og vi har begrænsede erfaringer med denne type spørgeskemaer.

Supplerende kommentar:

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Life cycle inventory and risk assessment of genetic modified perennial ryegrass in a technology foresight perspective.

Kristian Borch, Birgitte Rasmussen, Lotte Schleisner

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Abstract (max. 2000 characters)

Due to the complexity and advanced nature of modern biotechnology and to its content of risk and ethic matters it is necessary to face the challenge of making the prospect comprehensible and transparent to society. Using life cycle inventory (LCI), expert panels and weighted expert questionnaires, a methodological approach is suggested to analyse the uncertainties that the biotech industry and the authorities face when implementing genetically modified (GM) crops. These uncertainties embrace scientific rationality regarding technological development and risk assessments, as well as ethic political and social matters, which are based on more dispersed matters. In a test case on the development of a GM-ryegrass (that is incapable of producing stems and flowers during grassland farming) incorporated answers to a questionnaire from different types of experts and stakeholders identified four drivers as the most important and uncertain factors for the future direction of GM crops: 1) public participation in regulation, 2) utility value for the consumers, 3) being first to market GM-ryegrass, and 4) an efficient professional network. Based on the identified drivers several scenarios were constructed, of which two are presented in the report.

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